New Control & Fault Detection Methods for HVAC Systems

John E. Seem, Ph.D.

Agenda

- Sequencing Control
- Adaptive Feedback Control
- Fault Detection & Diagnostics

JCI Research: Tim Salsbury, Ashish Singhal, John Seem

- Diagnostics/Commissioning
  - Test Signals: setpoint changes, manual overrides
  - No test signals: observe normal operation
- Control
  - Local Loop: Adaptive
  - Supervisory: Sequencing, Demand limiting, ...

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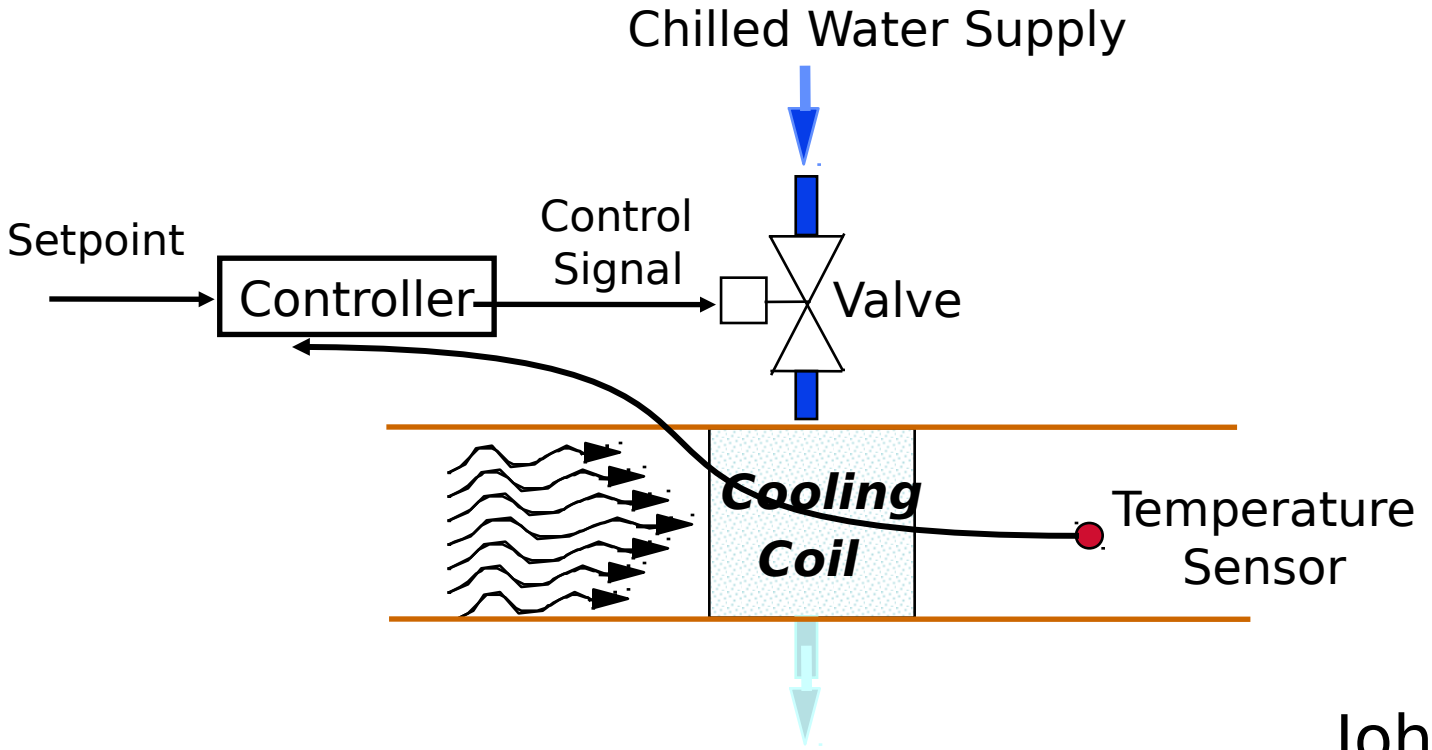
Feedback Control System



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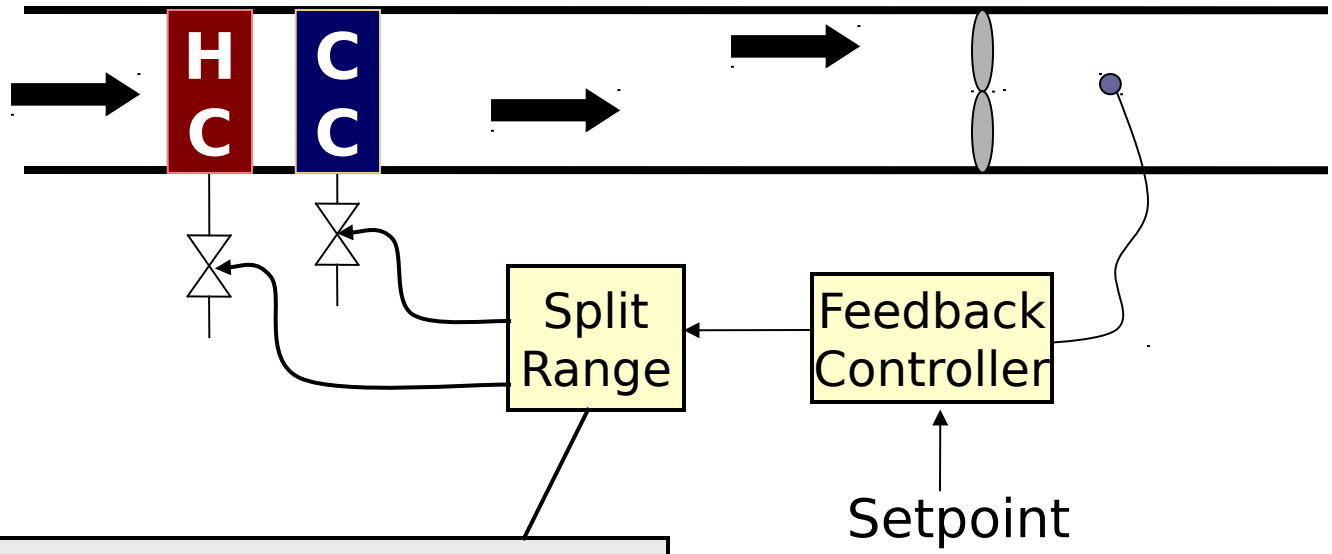
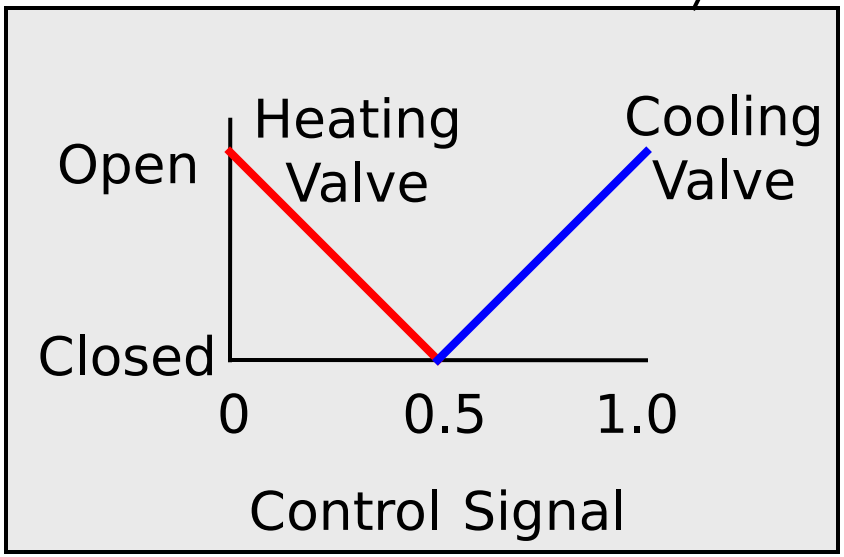
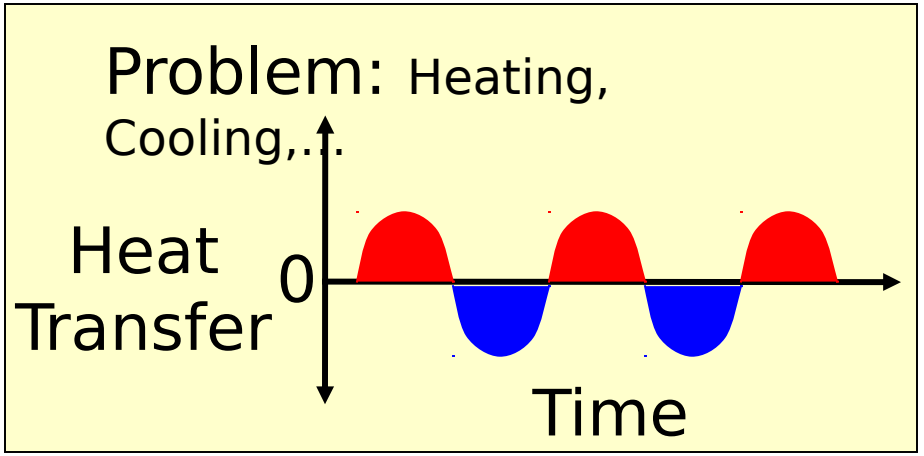
Split Range Control







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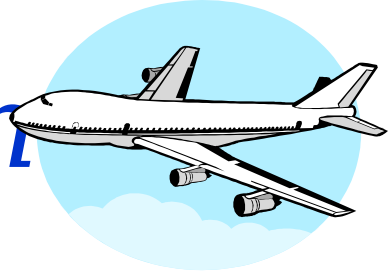
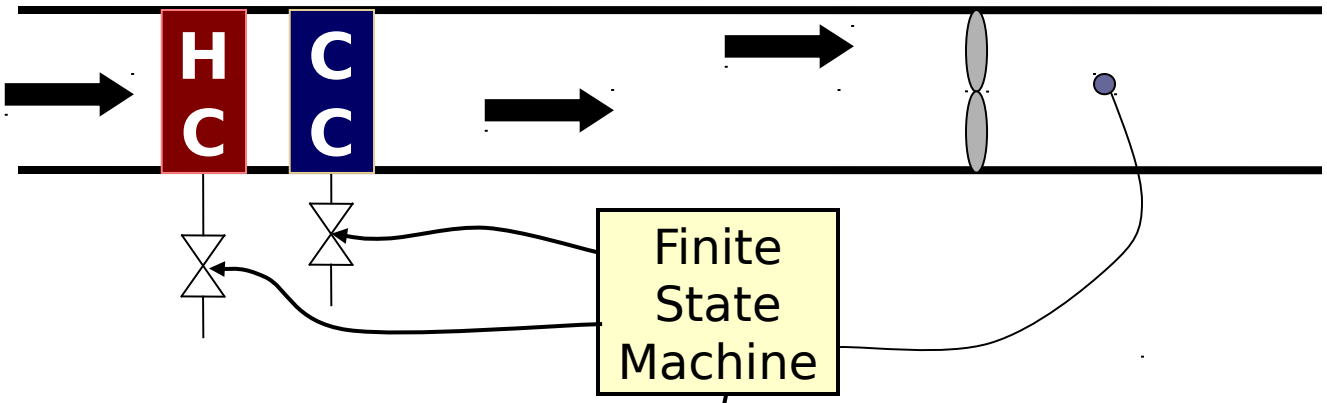
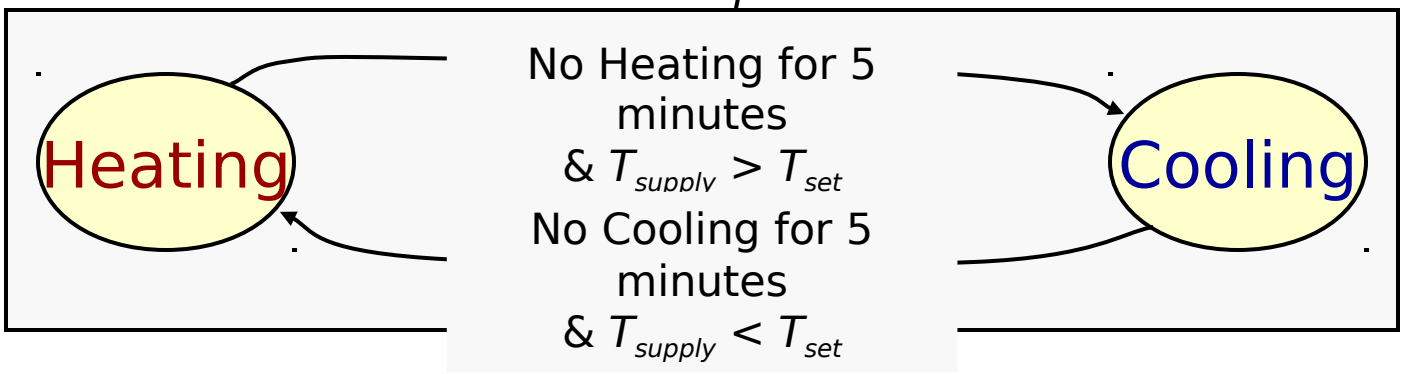
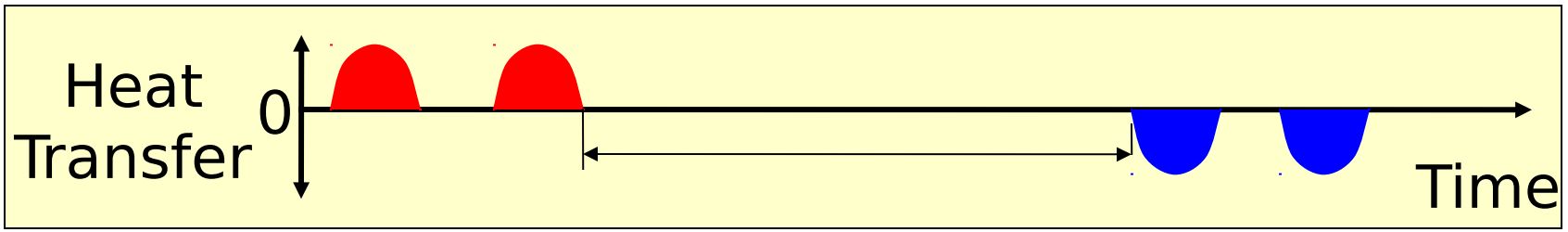
Finite State Machin









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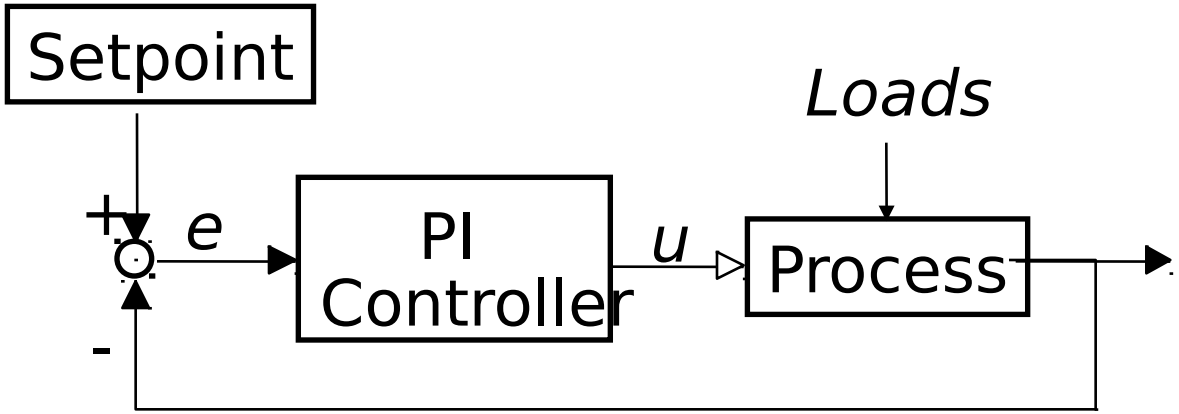
PI Controller



Gain

$$u(t) = \bar{u} + K\left[e(t) + \frac{1}{\tau_I}\int_0^t e(t^*)dt^*\right]$$

Integral Time

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Problem

Although PID Controllers are common and well known, they are often *poorly tuned*.

Åström and Hagglund (198

Automatic Tuning of PID Controllers

Journal of Control

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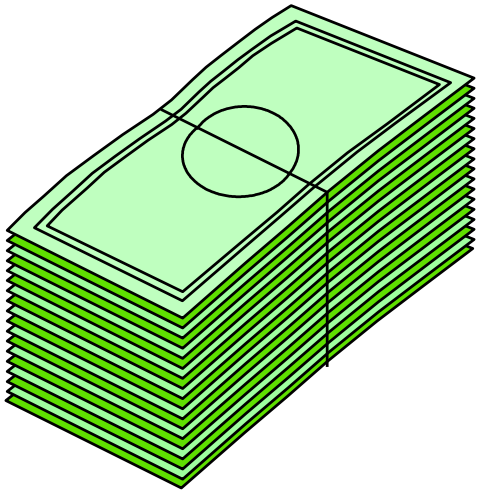
Potential Solutions

- Autotuning: Tuning on Demand

- Adaptive Control: Continuous Tuning



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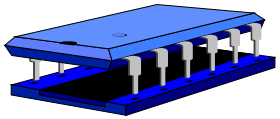
Background PRAC

- Continuous tuning for PI controllers
- Features
  - Easy to use
  - Near-optimal performance
  - Robust
  - Low  requirements
- Laptop Tuning Tool
- PRAC in over ½ million controllers

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Research Objective PRAC+

- Correct PRAC problems:
  1. Under-capacity systems restarted
  2. Extremely high controller gain
  3. Periodic disturbances
  4. On-off & staged equipment

- Add rules & logic to PRAC

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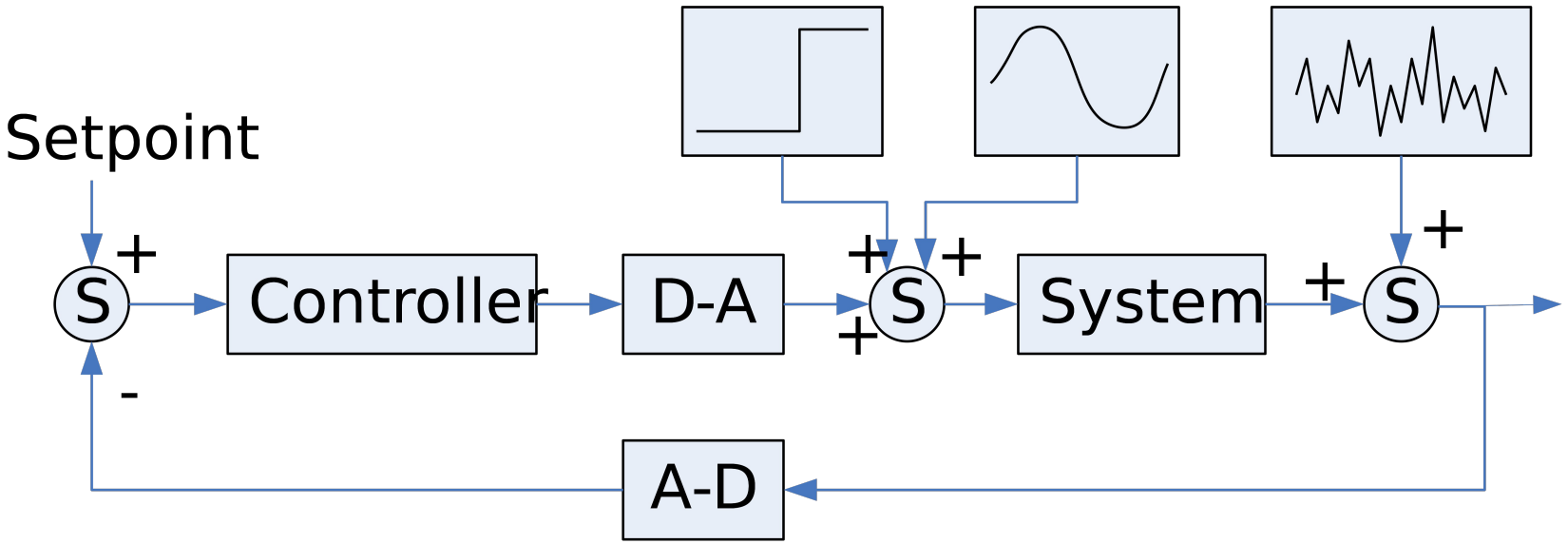
Control System Simulation



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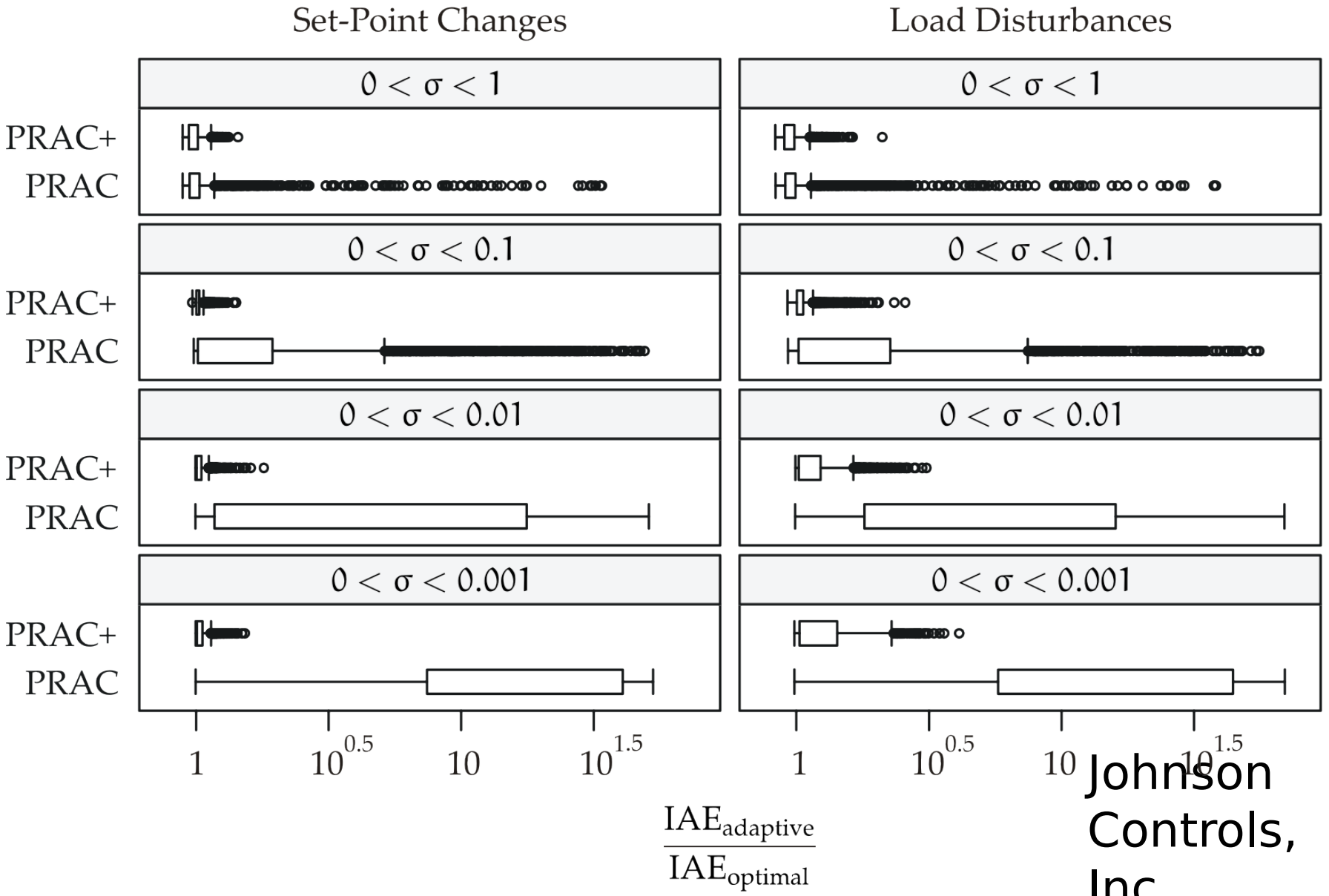
Periodic & Step Disturbances



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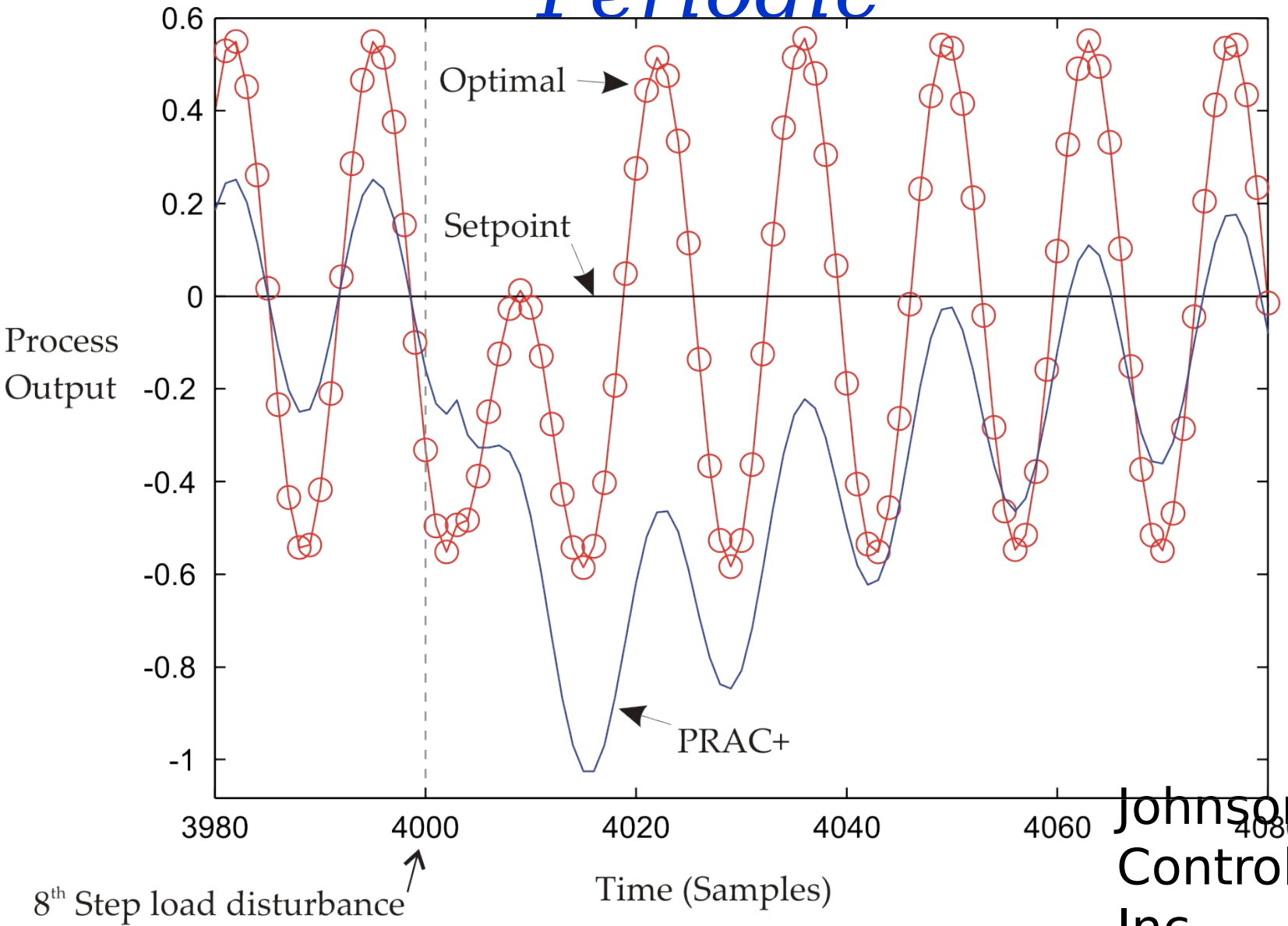
Worst performance: Step & Periodic



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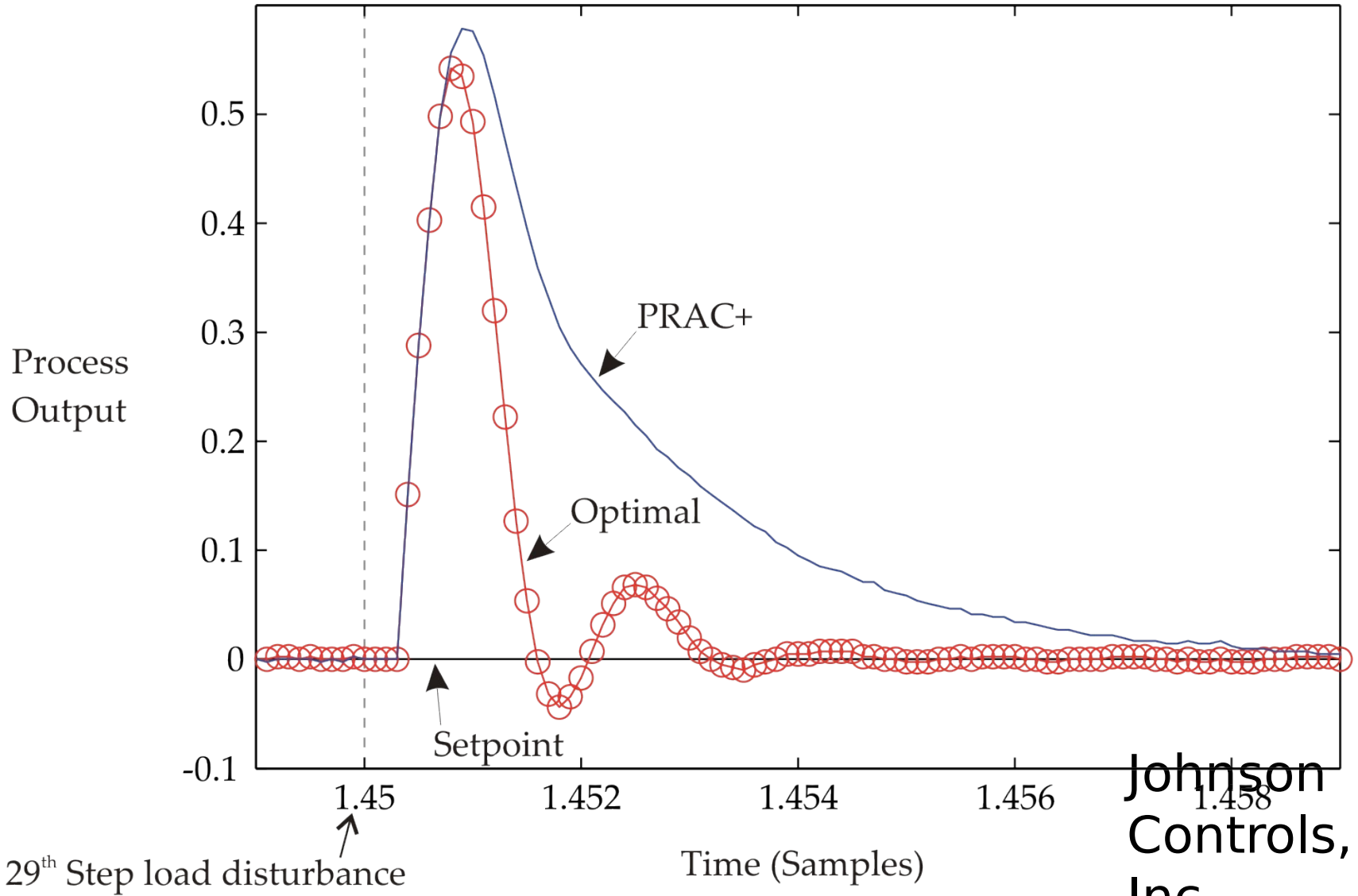

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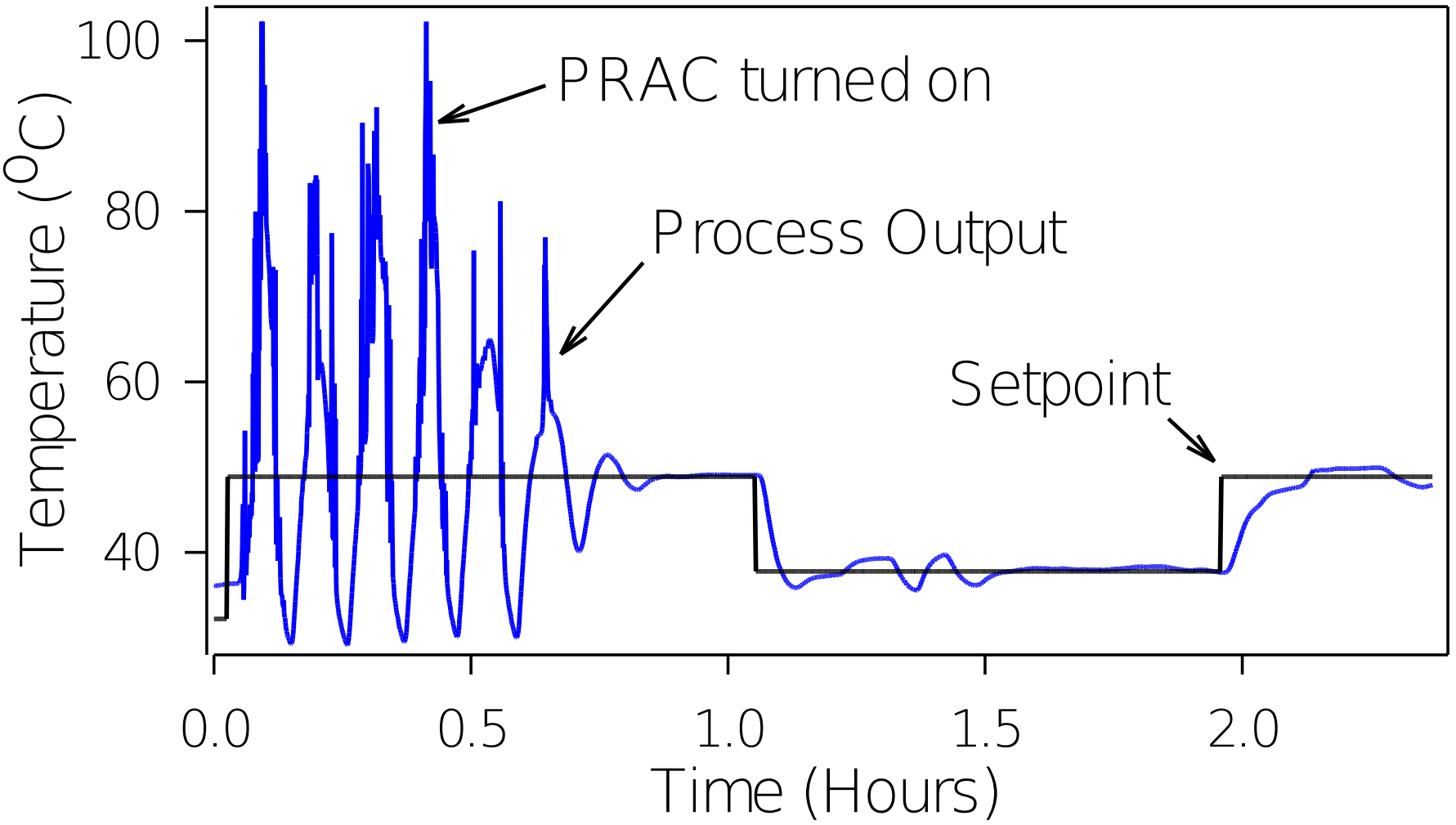
Field Test: Heating Coil



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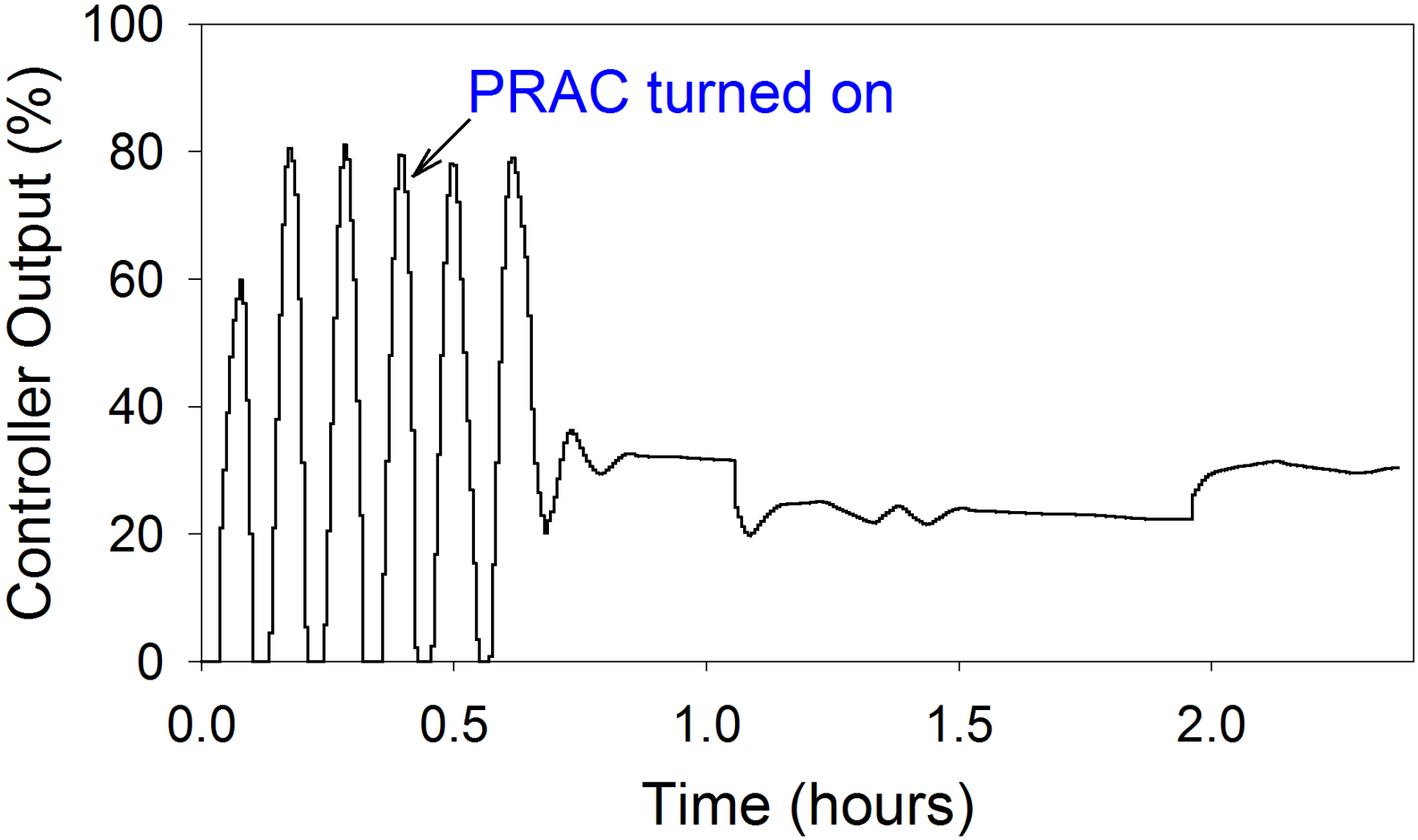
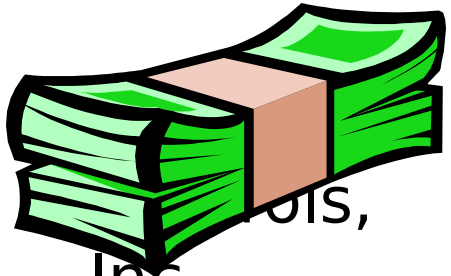
Field Test: Heating Coil



Problem: HVAC Control Systems

- Occupants detect many problems
- Data Overload
- Alarm Systems: operator set levels
  - Tight Alarm Levels: Too many false alarms
  - Loose Alarm Levels: No alarms
- Trend Graphics
  - Continuous Monitorin



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HVAC Fault Detection Research

- Active Research Area
  - IEA Annex 25 & 34
- Approaches
  - Whole Building Level
  - Component Level
- Difficulties
  - Not many sensors
  - Custom built systems
  - Many control methods
  - Low computational resources
  - Many faults: Planning, Design, Installation, Commissioning, Equipment, Control System

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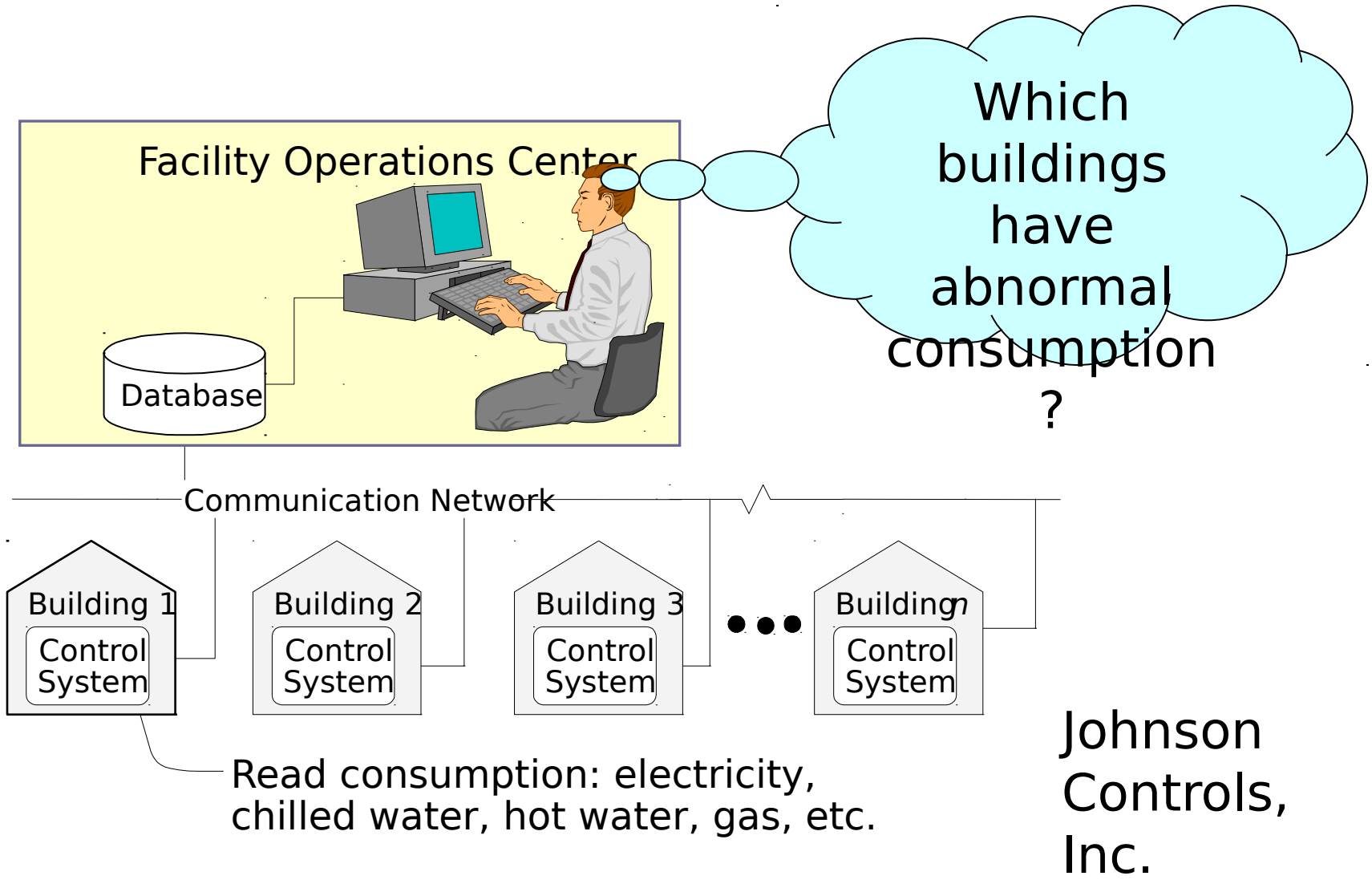
Whole Building Fault Detection



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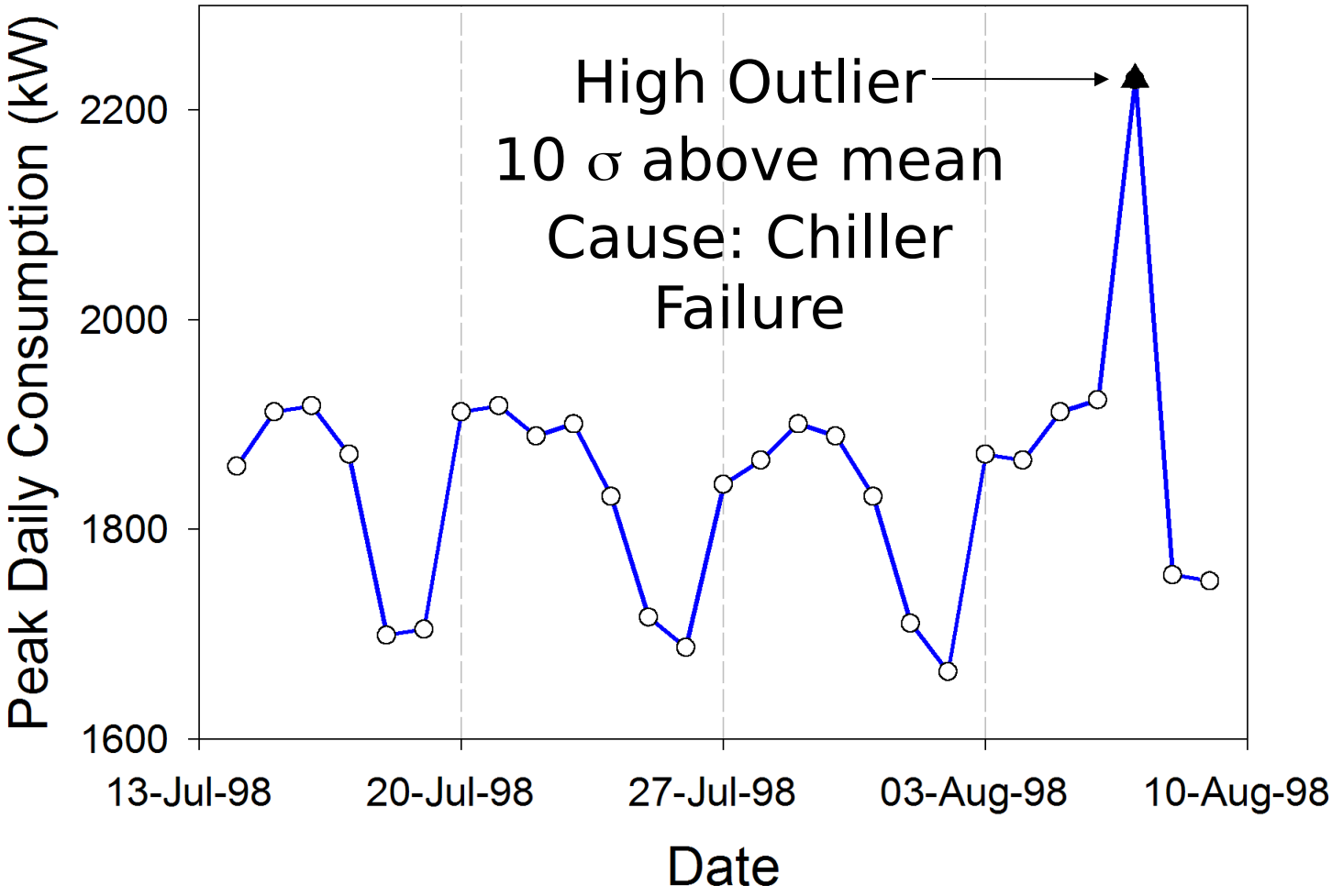
Chiller Fault



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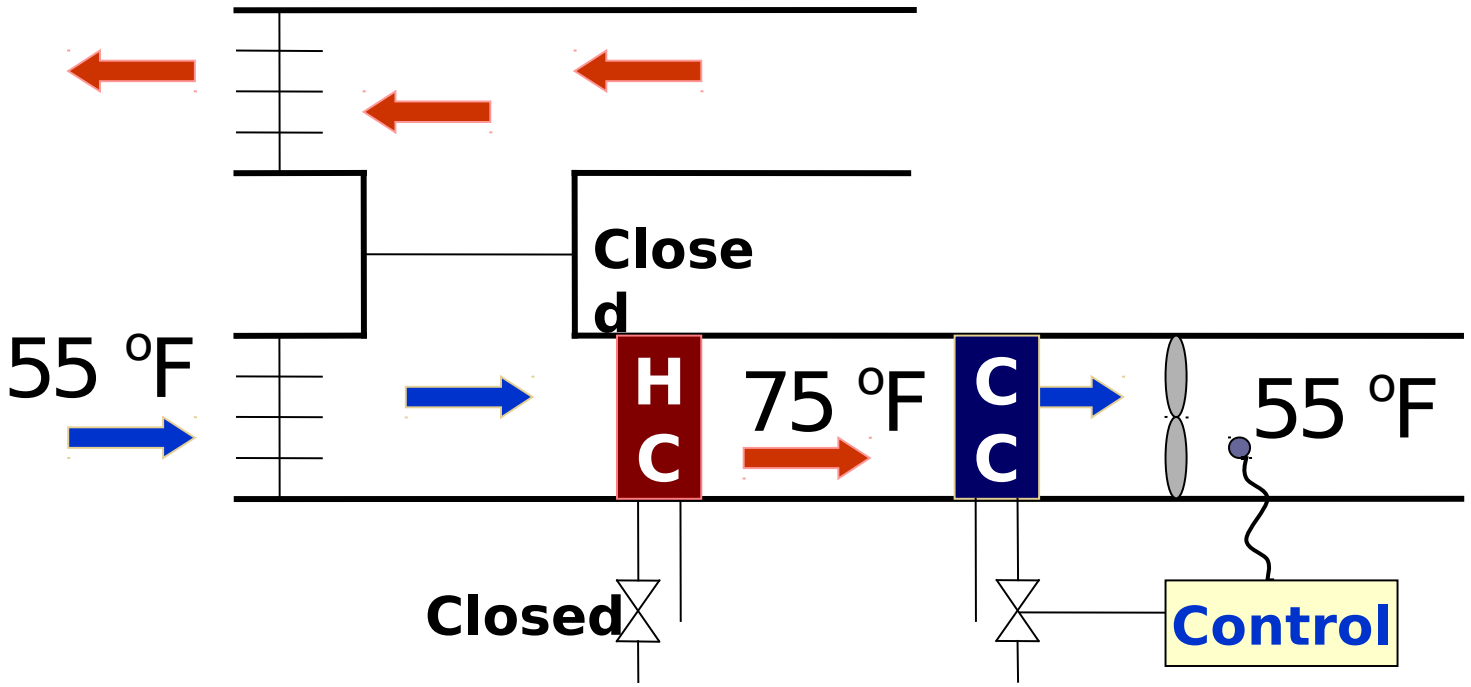
AHU Fault Detection

With Dr. John House *National Resources Canada*



Research Objective

- **Detect leaky valves, stuck dampers, …**
- **No additional sensors**

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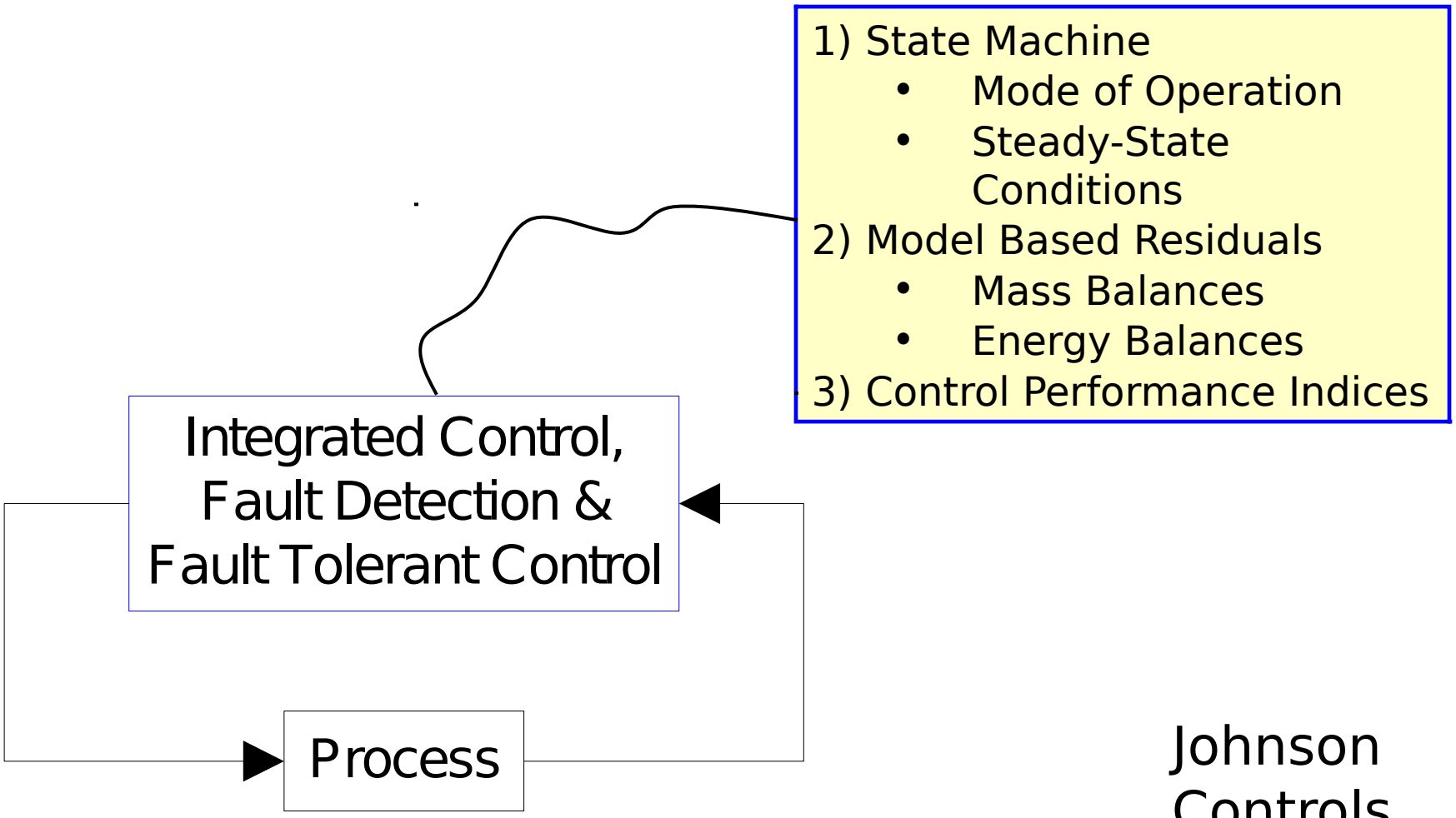
Approach for AHU Fault Detection



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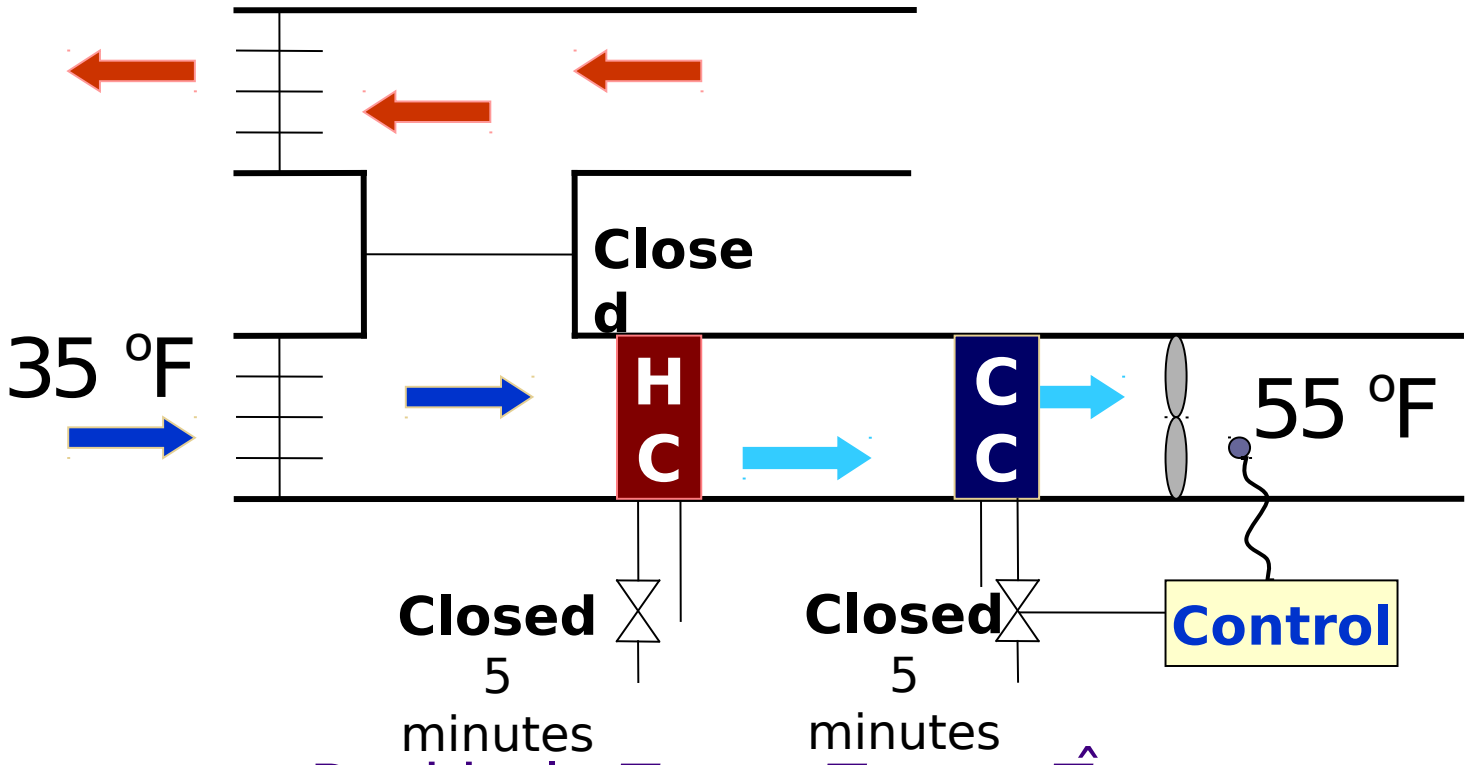
Residual Generation



Residual $= T_{supply} - T_{outdoor} - \hat{T}_{fan}$

$= 55\ ^0F - 35\ ^0F - 1\ ^0F$

$= 19\ ^0F$

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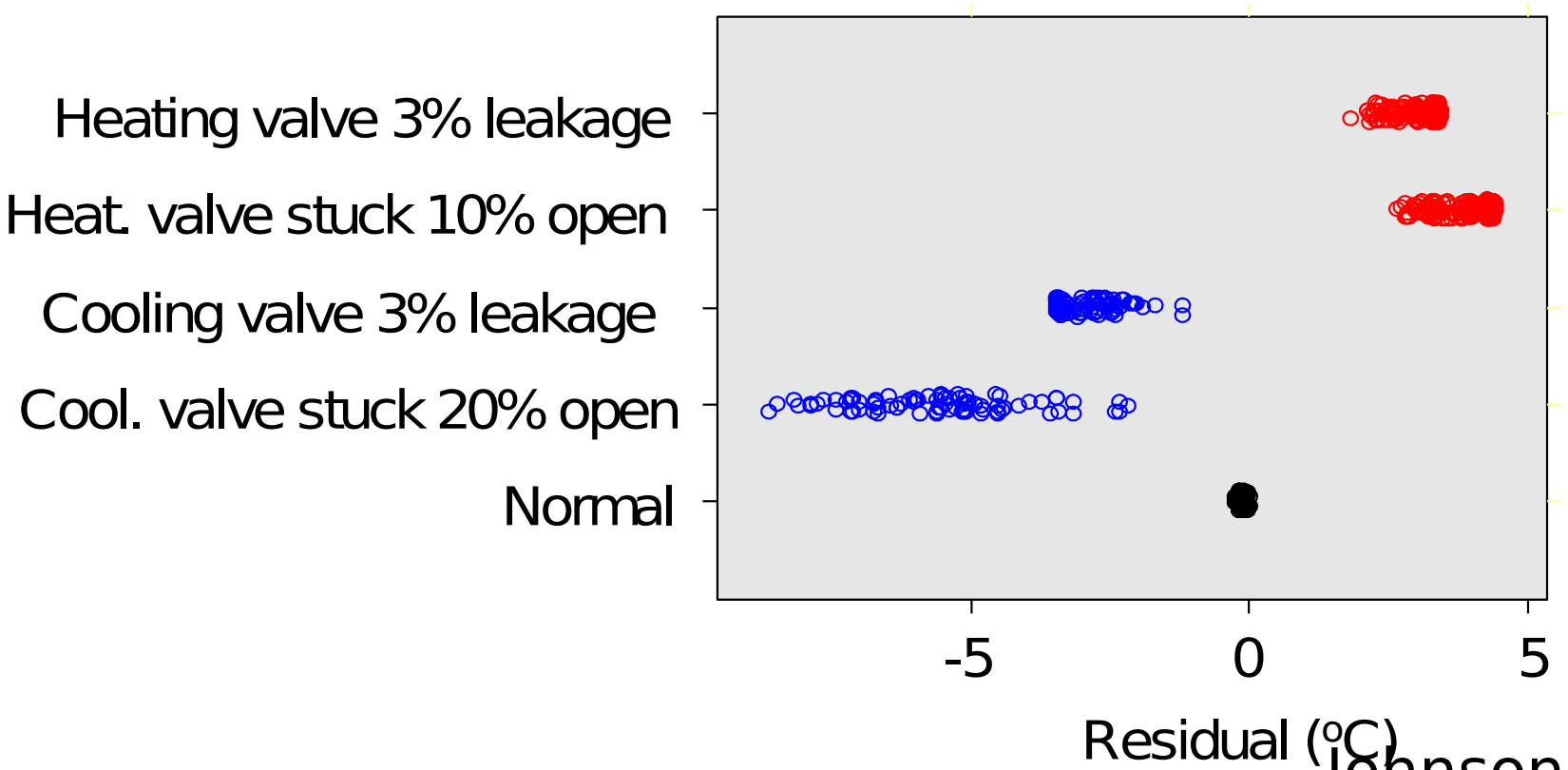
Simulation Results



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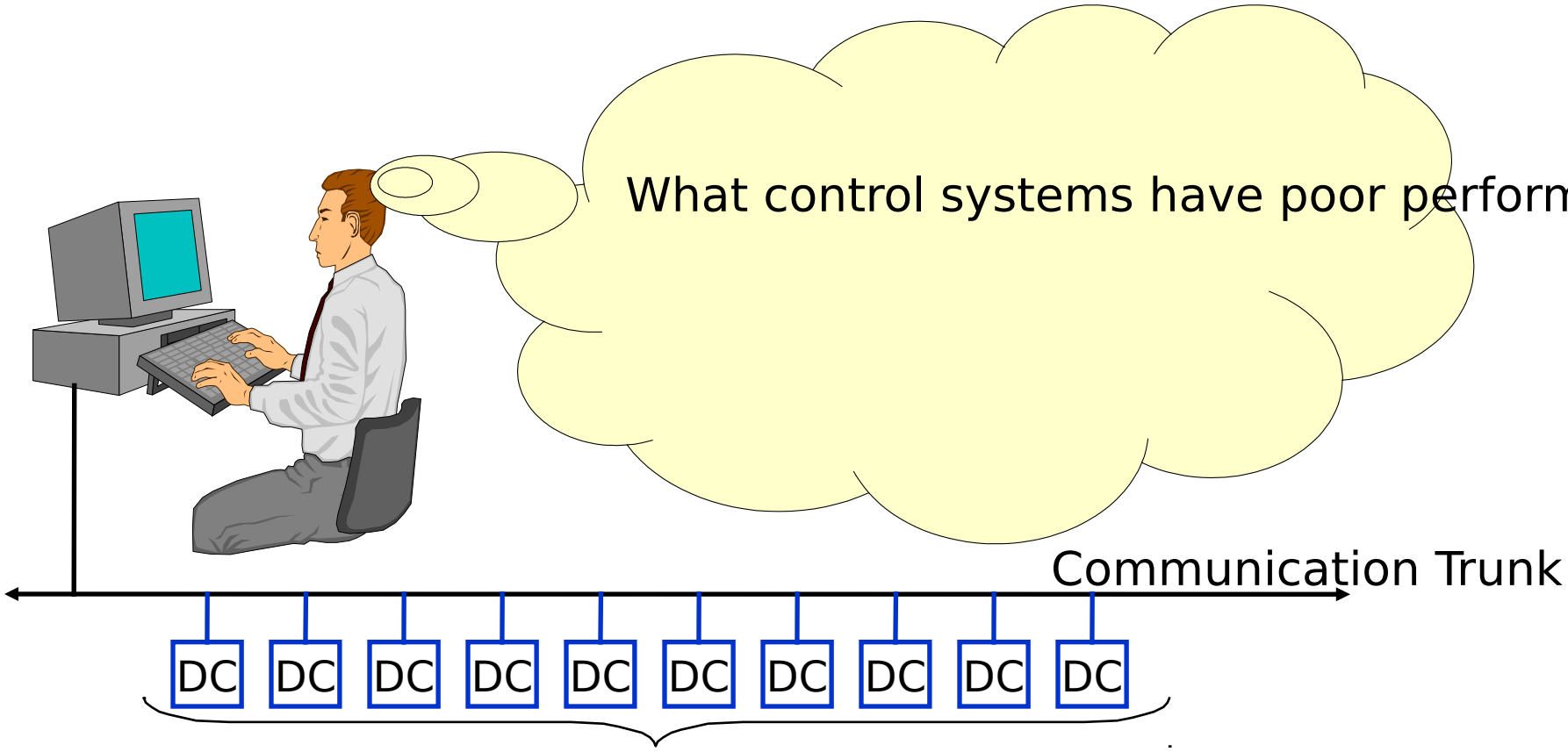
Control Performance Indices



Digital Controllers
(Connected to Sensors and Actuators)

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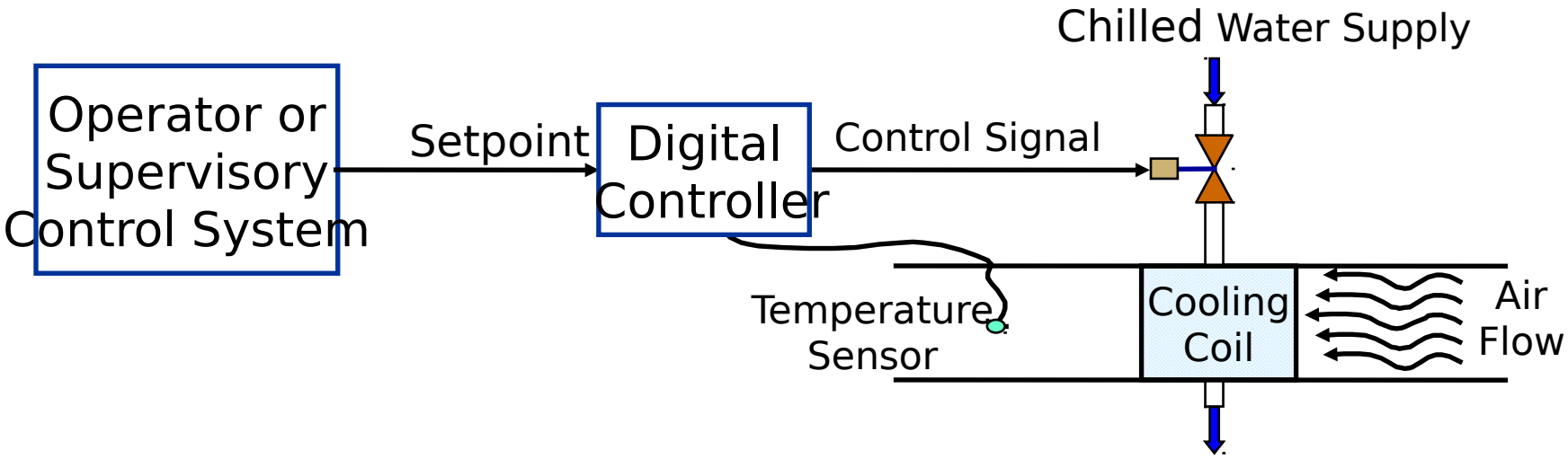
Feedback Control System



Wear = *f* (actuator movement)

Performance = *f* (setpoint - measured temperature)

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Performance Indices

1) Compute EWMA's of performance indices

Smoothed value at time t

Actual value at time t

$$x_t = x_{t-1} + \lambda(x_t - x_{t-1})$$

Smoothing constant

2) Select smoothing constant from

Sampling period

$$\frac{T}{5t_s} > \lambda > \frac{T}{20t_s}$$

Desired settling time

Performance Indices

- error
- |error|
- process output
- setpoint
- |change in controller output|
- controller output
- duty cycle
- starts, stops, and reversals

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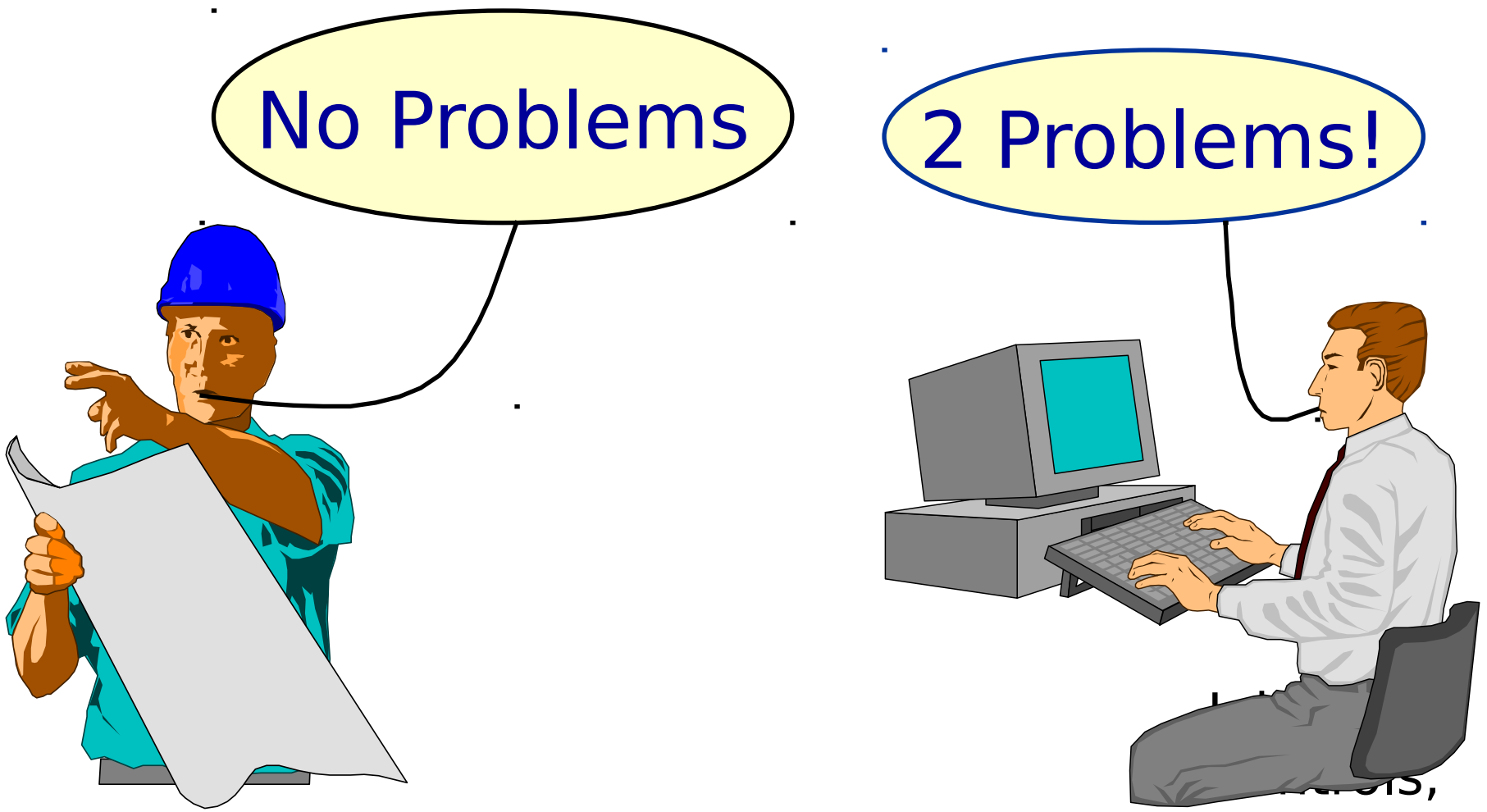
Field Test: 24 dual-duct VAV controllers



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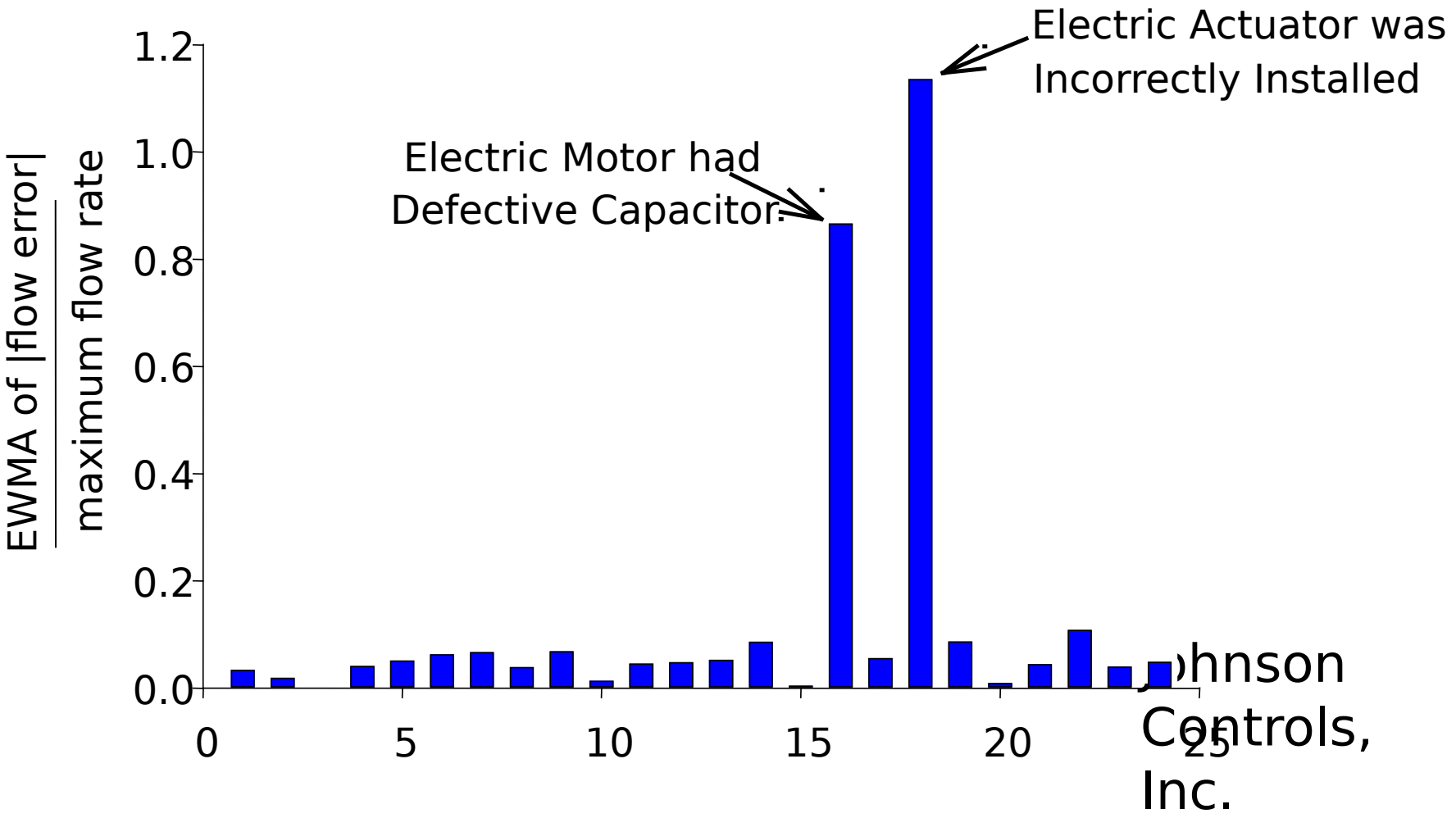
Normalized Flow Errors



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Summary

- Stop fast switching: H⇨C ⇨H ⇨C ⇨H ⇨C
- Tune feedback controllers
- Detect & fix faulty systems

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